NAG5-8145

New Data Source for Studying and Modelling the Topside Ionosphere

ABSTRACT

The existing uncertainties about the electron density profiles in the topside ionosphere, i.e., in the height regime from hmF2 to ~2000 km, requires the search for new data sources. Millions of ionograms had been recorded by the ISIS and Alouette satellites in the sixties and seventies, that never were analyzed in terms of electron density profiles. In recent years an effort started to digitize the analog recordings to prepare the ionograms for computerized analysis. This paper shows how the digital ionograms are processed and the electron density profiles (from satellite orbit altitude, 1400 km for ISIS-2, down to the F peak) are calculated.

The most difficult part of the task is the automatic scaling of the echo traces in the ISIS ionograms. Unlike the ionograms from modern ionosondes, the ISIS ionograms do not identify the wave polarization of the different echo traces, so physical logic must be applied to identify the ordinary (O) and extraordinary (X) traces, and this is not always successful. Characteristic resonance features seen in the topside ionograms occur at the gyro and plasma frequencies. An elaborate scheme was developed to identify these resonance frequencies in order to determine the local plasma and gyrofrequencies. This information helps in the identification of the O and X traces, and it provides the starting density of the electron density profile.

The inversion of the echo traces into electron density profiles uses the same modified Chebyshev polynomial fitting technique that is successfully applied in the ground-based Digisonde network. The automatic topside ionogram scaler with true height algorithm TOPIST is successfully scaling ~70 % of the ionograms. An 'editing process' is available to manually scale the more difficult ionograms.

The home page for the ISIS data project is at http://nssdc.gsfc.nasa.gov/space/isis/isis-status.html. It provides access to, as of January 2001, 300,000 digitized ISIS ionogram data and to related software. A search page lets users select data by location, time, and a host of other search criteria. The automated processing of the ISIS ionograms will begin later this year and the electron density profiles will be made available from the project home page. The ISIS data restoration efforts are supported through NASA's Applied Systems and Information Research Program.

Xueqin Huang, Bodo Reinisch

Center for Atmospheric Research

University of Massachusetts Lowell

Dieter Bilitza

Raytheon ITSS,

GSFC, Code 633, Greenbelt, MD 20771, USA

Robert Benson

NASA, Goddard Space Flight Center,

Code 692, Greenbelt, MD 20771, USA

Saving a Unique Data Set - The ISIS Story

1969 – 1990 *ISIS 1* launched in **1969** and *ISIS 2* launched in **1971** were operated by NASA until **1979**, then by CRC (Canada) until **1984** and finally by RRL (Japan) until **1990**. International participation - telemetry services, iongram reduction. Instruments: Topside Sounder, VLF, EPD, IMS, SPS, RPA, Photometers

1992 **- Mayday - Mayday -** (G. James, CRC) - The Candian Public Archive was getting ready to discard the more than 100,000 Alouette and ISIS telemetry tapes.

1993 **ITM Data Evaluation Panel** (D. Bilitza, Chair) selects the ISIS digitization project as its highest priority data restoration project.

1995 Some **13,800** Alouette and ISIS analog telemetry tapes were selected and shipped to GSFC. All but an additional ~ 4000 selected tapes have been destroyed.

1996 **Processing begins**; Analog tapes are read and digitized (R. Benson, PI, GSFC) and made online available fromNASA's National Space Science Data Center (NSSDC).

2000 Topside Ionogram Scaling and True Height Algorithm (**TOPIST**) software developed for automated scaling and inversion of ISIS ionograms.

2001 TOPIST processing of the more than **300,000 digitized ISIS-2 ionograms** begins

« Global mapping of the topside ionosphere over more than a solar cycle »

Digitization of ISIS Ionograms at GSFC

System Used: **The digitization system uses a 486-based Programmable Telemetry Processor (PTP), an A/D converter board and a software device driver compatible with the OS2 operating system used by the PTP. During the A/D operation, ionogram frame sync pulses are identified, flagged and the corresponding PB4 time code is determined. The PB4 time code is the output of a time-decoder card which receives the NASA 36-bit time code (added at the telemetry station) as the input. The ionogram line sync pulses are also identified and flagged. These line-sync flags are used to identify the start of columns for data arrays used to generate digital ionograms. The flags are stripped off during the process of setting up these arrays.**

• RATE/VOLUME • Since processing started in 1996 ISIS-2 ionograms have been digitized at a rate of 5000 per month (7 GBytes) producing, as of December 2000, a total of more than 300,000 ionograms and a total data volume of 450 GBytes.

Data Products:

• Ionogram (3.75 km apparent-range (full) resolution), orbit parameter, OS2 binary

The digitized sounder data consists of 8-bit receiver-amplitude values collected at a 40 kHz (0.025 ms) rate and the related echo times and frequencies. The frequency of each sounder pulse is determined from a 3rd degree interpolation between the times of the frequency markers as identified in the sounder video during the A/D operation.

• Ionogram (15 km apparent-range (standard) resolution), orbit parameter, OS2 binary

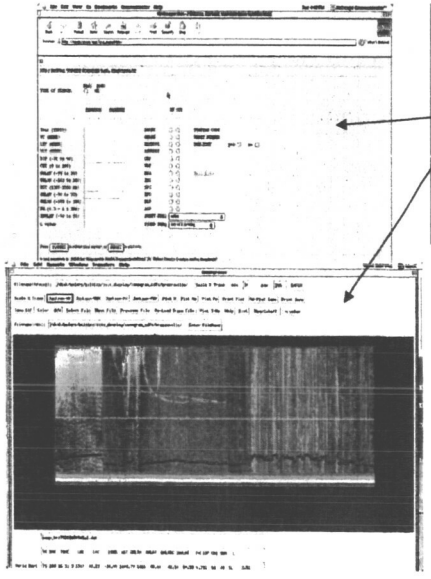
This data set is an average over four of the 'full' resolution data points. Typical size is 250-500 Kbyte, whereas the full ionograms require typically 1-2 Mbytes.

• Header files, one per pass/tape, pass information and headers for all pass ionograms, ASCII

• PCM, Pulse Code Modulation, one per pass, OS2 binary

Consists of header, time, Automated Gain Control, frequency-marker information and data from all other instruments.

Data, Software, and SearchPage

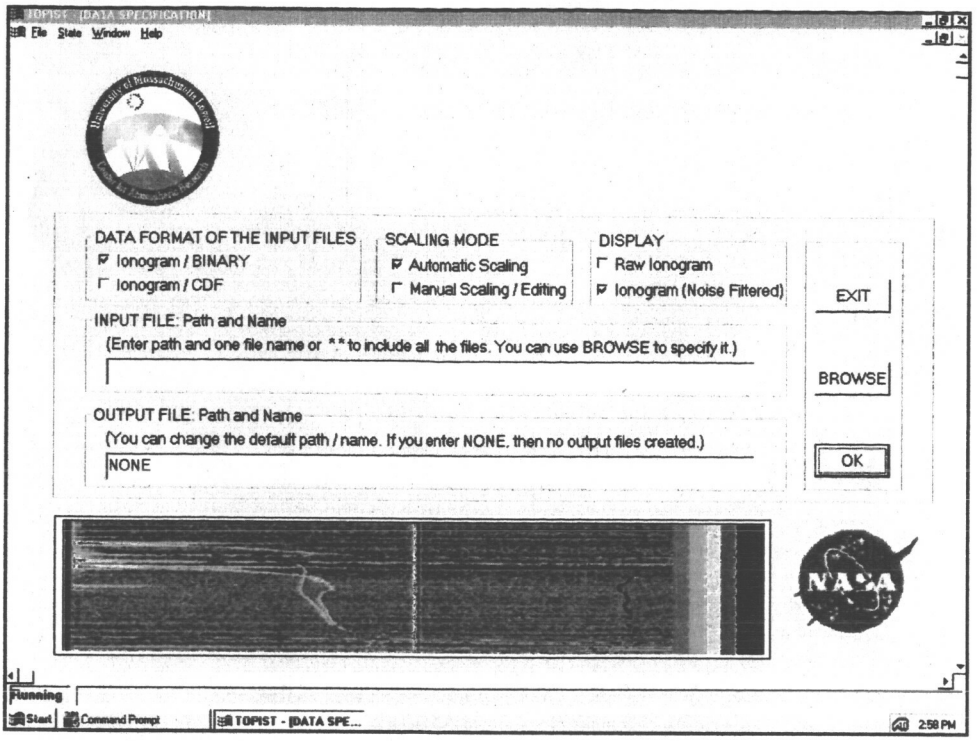


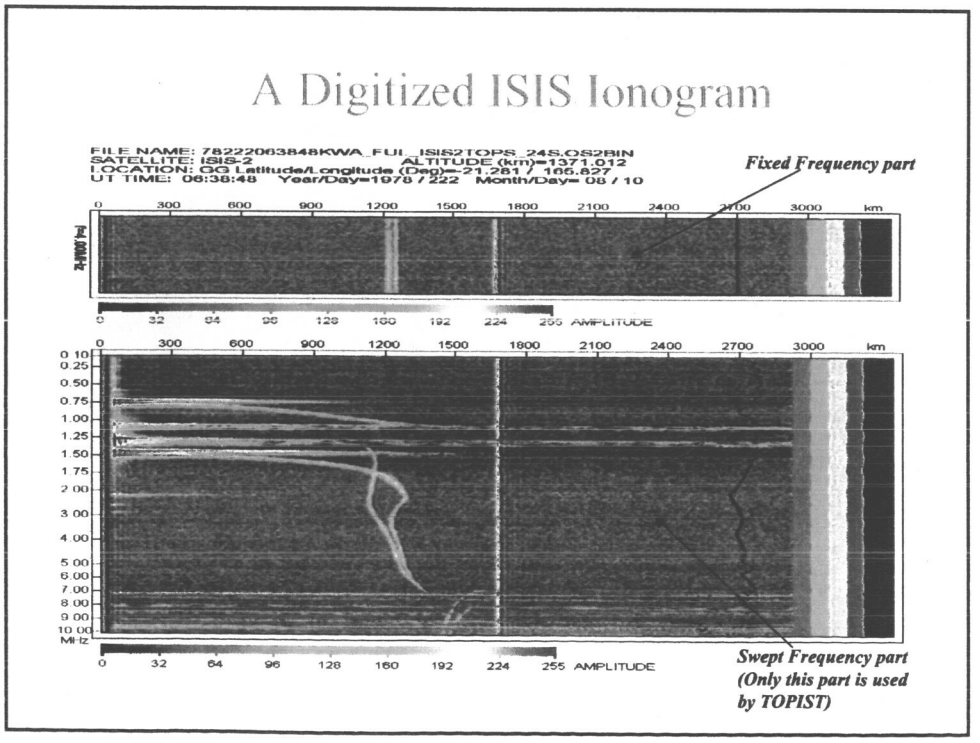
Available Online from NSSDC:

- **All digitized ISIS ionograms (full and sta. res.), OS2 binary**
- **All sta-res. ionograms in CDF format (created at NSSDC)**
- **The header files, ASCII (PCM files are stored offline)**
- **A Webinterface for searching for specific times, locations and other criteria (developed by R. Benson and team)**
- **An interactive scaling and inversion program (R. Benson)**
- **The Worldmap program for computing orbit parameters**
- **A selection of ionogram (about 1/10) is available for viewing on CDAWeb (plans for making all data available)**

Total number of passes:	**9,854**
Total number of ionograms:	**302,809**
Total data volume (all files):	**457 GB**

Dec 2000


TOPIST - [DATA SPECIFICATION]
File State Window Help
DATA FORMAT OF THE INPUT FILES
Ionogram / BINARY
Ionogram / CDF
SCALING MODE
Automatic Scaling
Manual Scaling / Editing
DISPLAY
Raw Ionogram
Ionogram (Noise Filtered)
EXIT
INPUT FILE: Path and Name
(Enter path and one file name or *.* to include all the files. You can use BROWSE to specify it.)
BROWSE
OUTPUT FILE: Path and Name
(You can change the default path / name. If you enter NONE, then no output files created.)
NONE
OK
NASA
Running
Start
Command Prompt
TOPIST - [DATA SPE...
2:58 PM


A Digitized ISIS Ionogram
FILE NAME: 78222063848KWA_FUL_ISIS2TOPS_245.OS2BIN
SATELLITE: ISIS-2 ALTITUDE (km)=1371.012
LOCATION: GG Latitude/Longitude (Deg)=-21.281 / 166.827
UT TIME: 06:38:48 Year/Day=1978 / 222 Month/Day= 08 / 10
Fixed Frequency part
0 300 600 900 1200 1500 1800 2100 2400 2700 3000 km
0 32 64 96 128 160 192 224 255 AMPLITUDE
0.10
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
MHz
Swept Frequency part
(Only this part is used
by TOPIST)

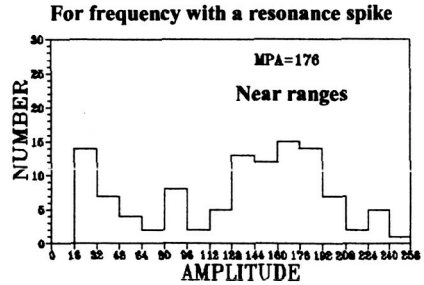
PROCESSING PROCEDURE

- **Reading Ionogram Data File**
  - Full or average ionograms, OS2 binary
- **Noise Filtering**
  - Done independently for each frequency line
  - Two "Most Probable Amplitudes" are determined (for the close and for the far range) and the smaller is selected as noise threshold
- **Identification of Resonance and Cutoff Frequencies**
  - Five-frequency comb window with fNs as a free variable; Slide along frequency axis and find maximum amplitude cases
  - Three most-likely sets are determined and the best one is selected in the "auto-scaling of traces"
- **Modeling the F layer peak**
  - foF2 and hmF2 values are calculated from URSI and CCIR coefficients and serve as guide for the auto-scaling
  - Ground returns, if observed, are used as one boundary for the peak search
- **Automated Scaling of Traces**
  - Find potential trace points for each frequency line storing their amplitude and connection length to neighbors
  - Find optimal combination of resonance/cutoff frequencies and o- and x-traces using a family of generic functions
- **Inversion to Electron Density Profiles**
  - Introducing a reduced frequency variable and representation with Chebyshev polynomials
  - Works with o-trace only, or x-trace only, or both traces and possibly the z-trace

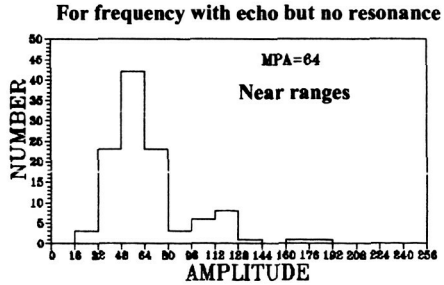
Noise filtering:

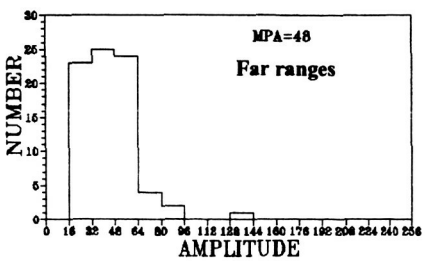
Amplitude histograms

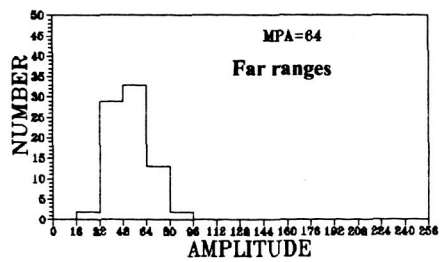
For frequency with a resonance spike



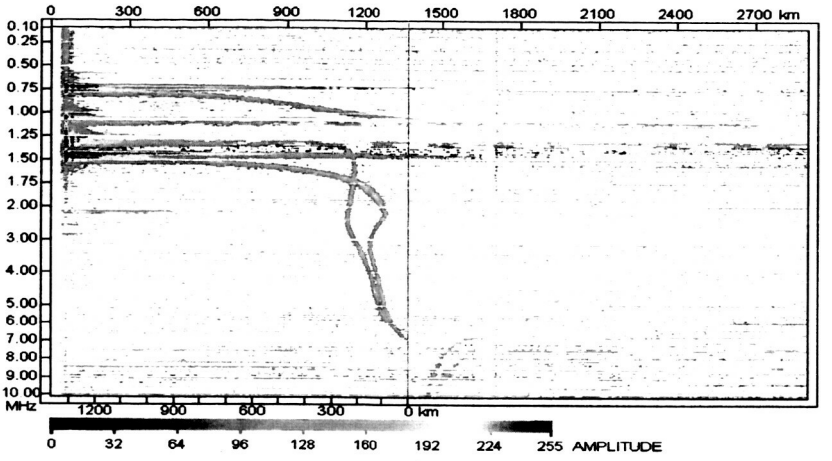
For frequency with echo but no resonance



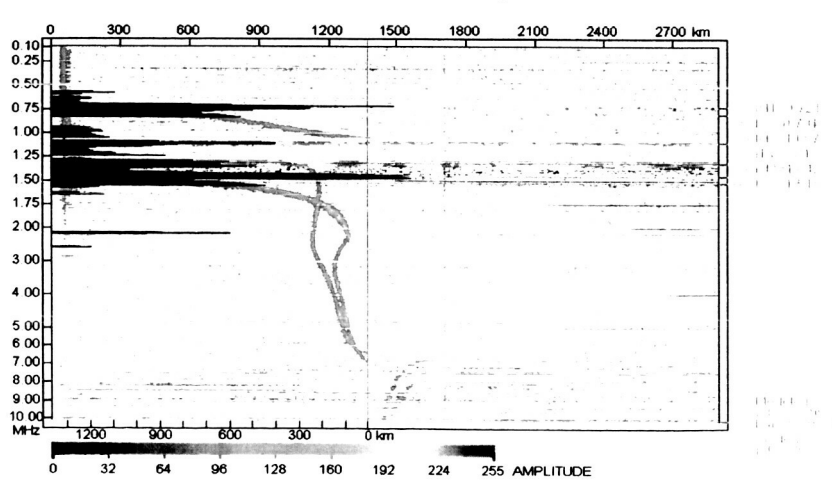




Noise-filtered Ionogram



Finding Resonance and Cutoff Frequencies

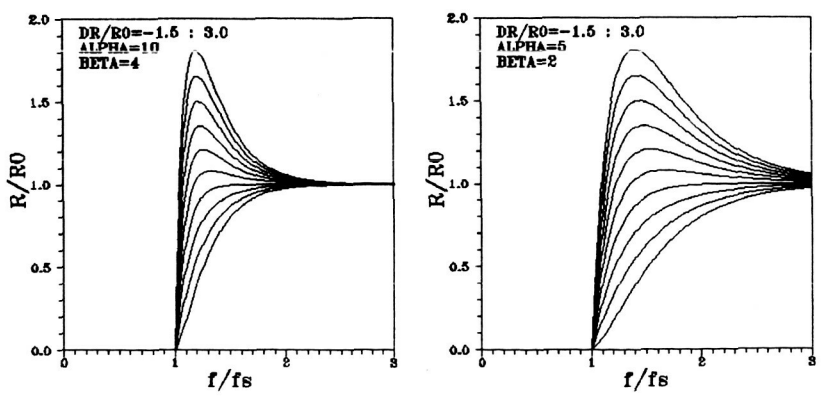


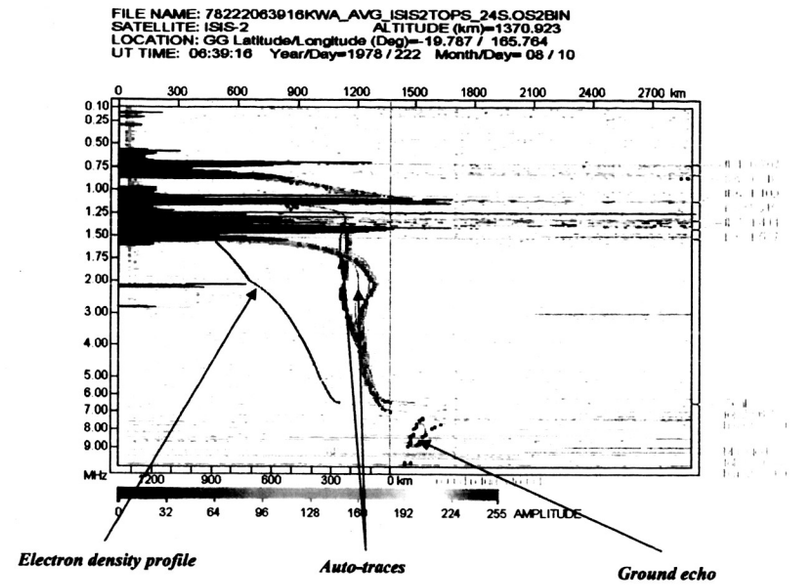
Automatic Scaling of Traces

- Determine the possible trace points for each frequency line and get the the connection length to the nearest neighbors.
- Select the most likely points for inversion and identify the polarization (O/X) using an iteration technique.
- Select the best set of resonance and cutoff frequencies
  - *Principle: Minimize the inversion error (error per point) for the largest possible set of trace points*
- Fit generic function to trace

Fitting generic function to trace

$$R = R_0 - \{[R_0 + DR] \cdot \exp[-a \cdot (f - f_s)] - DR \cdot \exp[-b \cdot (f - f_s)]\}$$





Inversion of traces to electron density profiles

The apparent range p' for the frequencies f_k assuming an electron density N(z):

$$p'(f_k) = \int_0^{Z_r} \mu'[N(z), f_k, fH(z), \phi(z)]\, dz$$

μ group index of refractive media
fH(z) gyrofrequency
Ø dip angle

Defining a reduced frequency:

$$f'^2_k = \begin{cases} f_k^2 & \text{for O-trace} \\ f_k^2 - f_k * fH & \text{for X-trace} \\ f_k^2 - f_k * fH & \text{for Z-trace} \end{cases}$$

$$f'_k = fN(Z_r)$$

and new variable

$$t^2 = \frac{f'^2_k - fN^2(z)}{f'^2_k - fN_S^2}$$

Assume that Ne(h) can be represented with Chebyshev polynomials:

$$Z = A_m + g^{1/2} \sum_{i=0}^{L} A_i T_i^*(g), \quad \text{with} \quad g = \ln(fN/fN_m)/\ln(fN_s/fN_m)$$

Linear Equations for Coefficients

- The best coefficients in a least squares sense are found by minimizing the error

$$\Delta = \sum_{k=1}^{K} [\, p'_k - \Sigma A_i S_{ik} \,]^2$$

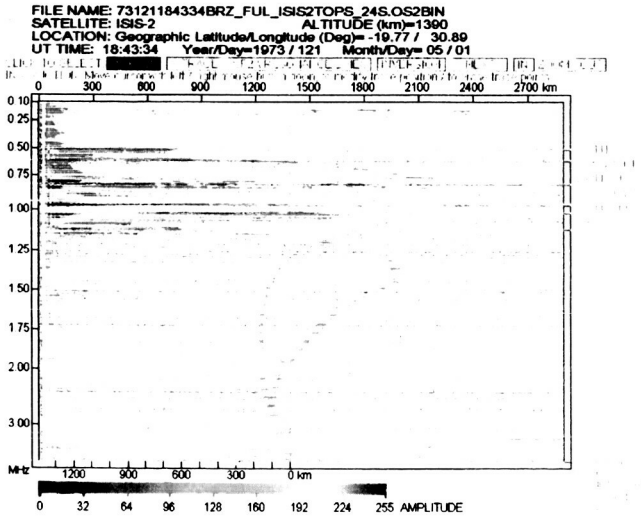
- Linear equations for coefficients

$$\sum_{i=0}^{I} A_i \, Q_{ij} = \sum_{k=1}^{K} P'_k \, S_{jk} \qquad j=0,1,\ldots I$$

$$Q_{ij} = \sum_{k=1}^{K} S_{ik} \, S_{jk}$$

Manual scaling

- **Cross-hair drags trace to new location**
- **Cross-hair drags 5-frequency comb along frequency axis**
- **Effect of trace changes on computed Ne(h) can be investigated.**
- **Ionograms rejected by the auto-scaling can be inspected and manually scaled.**



TOPIST Performance

- **Test data: ~800 digital ISIS-2 ionograms**
- **Current algorithm performance:**
  - *~70% of manually scalable ionograms are successfully autoscaled*
- **Auto-scaling failures are caused by:**
  - *Severe spread*
  - *Data missing for a large frequency interval*
  - *Existence of unidentified traces (oblique?)*
  - *Incorrect identification of resonances*
- **Inversion errors:**
  - *Ill-conditioned: No coefficients found*
  - *Non-monotonic profile found*
  - *Non-reasonable peak height found (<200km)*
- **Propagation modes:**
  - *The current TOPIST assumes that fH/f<1 (for ISIS-2 sounding) and both O and X modes exist. The Z-trace is recalculated*

Future Plans

- TOPIST testing and refining with a large number of ionograms from high and low latitudes.

- Routine processing of the more than 300,000 digitized ionograms into electron density profiles

Treasure chest for ionospheric modeling
- International Reference Ionosphere -

- ***IRI topside profile is based on ~ 40,000 profiles from Alouette 1***

- ***Inversion of the now digitized ~ 300,000 iongrams will more than quintuple the current holdings of topside electron density profiles***

- ***Better ionospheric predictions for high solar activities.***

- ***Better understanding of the plasma processes in the high latitude and low latitude topside.***